Management of Energy Technology Innovation Activities at the U.S. Department of Energy

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The management of energy-technology-innovation programs at the Department of Energy has a mixed record. There are several prominent "failures" such as the Synfuels and Clinch Breeder Reactor programs, and also a number of famous and notable successes. On balance, however, the National Research Council concluded in 2001 that, in the case of the fossil-fuel and energy-efficiency R&D programs the NRC study reviewed, the "benefits of these programs substantially exceed the programs' costs and contribute to improvements in the economy, the environment, and national security" (NRC 2001, 63).

Problems identified in the past with DOE's energy-technology-innovation activities include the narrowness of programs, inability to stop non-performing programs, poor coordination of activities across program boundaries ("stovepiping"), weak coordination of fundamental and applied RD&D, congressional earmarking, lack of clear leadership and authority, and limited technical skills among staff members. Significant progress has been made in recent years on many of these problems, particularly in the development of criteria for starting, continuing, and stopping projects; developing performance metrics for mid-stream review; soliciting external peer review; and establishing partnerships with the private sector and academia (including for cost-sharing arrangements).

The energy-efficiency and renewable-energy (EERE) program, for example, recently put more than two-thirds of its R&D funding through competitive solicitations, terminated more than 60 projects, and conducted more than 20 external peer reviews (SPR 2002). While such progress is commendable, the Commission suggests that further management reforms are both possible and necessary. In what follows here, we review briefly the recommendations of recent studies that have addressed management issues, discuss some major successes and failures and the lessons learned from them, and then offer our own conclusions on DOE management of the federal govenment's energy-technology-innovation efforts.

MANAGEMENT RECOMMENDATIONS OF PREVIOUS STUDIES

In its 1997 report on *Federal Energy Research and Development for the Challenges of the 21st Century* (PCAST 1997), the President's Committee of Advisors on Science and Technology addressed DOE management of energy R&D as well as budgets and opportunities. In 2001 the National Research Council likewise addressed management issues, along with its analysis of cost-benefit ratios, in *Energy Research at DOE: Was It Worth It?* (NRC 2001). In 2003, a task force of the Secretary of Energy's Advisory Board released a report, *The Future of Science Programs at the Department of Energy* (SEAB 2003), which likewise addressed management as well as other issues. The management recommendations of all of these reports were generally consistent and mutually reinforcing, although differing in in emphasis in certain respects.

The recommendations of these three reports are summarized in Figure 1 in a form that facilitates comparisons. Two common themes from the reports that deserve some elaboration here, before we turn to our own recommendations, are balancing of risks across an innovation portfolio and evaluating costs versus benefits of investments in energy-technology innovation.

Balancing Risk in Energy Innovation Portfolios

Managing innovation entails the management of a portfolio of investments in options at different stages of development, with different time horizons for potential commercialization, addressing different applications and challenges. Successes usually occur in the form of a few 'big hits' amidst many results whose value is uncertain at the time (and may turn out to be small, or even negligible) and some (sometimes spectacular) failures. Many R&D projects produce results that may appear to have little or no significance

by themselves but are important because, when they are brought together with the results of other R&D efforts, they permit significant advances and even breakthroughs. A portfolio and its management should be judged in terms of the results from the whole portfolio over time...and the appropriate time may be long. Anecdotal lists of past failures tell us little nothing about the value of the overall portfolio. If one insists that there be no failures, one only ensures that there no risks will be taken and, accordingly, that no big successes will result.

A common error in R&D management is the undertaking and continuing of projects and programs whose purpose (whether it be curiosity satisfaction, knowledge expansion, proof-of-concept, development, demonstration or test) is not really clear or is muddled by other motives. The challenge is to establish systems to encourage sound and transparent program assessments and feedback loops to ensure that lessons from prior successes and failures are taken into account. Ultimately, success will depend upon the skilled judgment of government officials. An important value of explicit decision criteria is to enable outside review and critique of ultimate decisions. It has been noted that, "The most important event in research is the prompt recognition of a dead horse, and its decent burial."

This is true, but, unfortunately for managers trying to apply the dictum, many a research horse given up for dead has turned out to be a race winner in the hands of a persevering trainer. A famous example is Alexander Graham Bell's telephone. Western Union rejected it because the company thought that anything that needed to be sent could be sent by telegraph, and, besides, no one would pay $5 just to talk to their grandmother in Indianapolis. It was only by an accident of publicity at the Chicago World's Fair a European dignitary visited Bell's booth and was interviewed there by reporters that set it on a useful road. There are failures of both kinds: going on too long and stopping too soon. Neither can be entirely prevented by even the best trainer; it's the trainer's total track record that counts (Frosch 2004).

Evaluating the Costs and Benefits of Past Efforts

The 2001 NRC report concluded that, as might have been expected, a relatively small number of DOE research programs in energy efficiency and fossil energy accounted for the majority of the economic and environmental benefits (NRC 2001, p 63):

> "This characteristic of RD&D programs, in which a few "home runs" are responsible for the majority of returns on investments, is shared by industrial R&D programs and underscores the importance of maintaining a diversified portfolio of investments. The areas in which these benefits were greatest relative to program expenditures include residential and commercial construction, an industry that historically was not particularly innovative, and technologies to reduce environmentally harmful pollution. These are precisely the areas in which one would anticipate that public R&D programs are most likely to prove most effective. By contrast, DOE efforts to push the technology to commercial application in large, accelerated RD&D programs such as coal liquefaction have been extremely risky and prone to cost overruns and generally have yielded relatively small benefits relative to their high costs."

The report estimated that total realized economic benefits associated with the energy-efficiency programs that it reviewed were in the $30 billion range, substantially exceeding the roughly $7 billion investment for energy-efficiency RD&D over the 22-year life of the programs (both in 1999 dollars). For fossil programs, the benefits exceeded costs in the 1986-2000 period (benefits of $7.4 billion and costs of $3.4 billion in 1999 dollars), but costs exceeded benefits in the earlier 1978-1986 period (benefits of $3.4 billion compared with $6 billion in costs in 1999 dollars).

We note that the period in which the DOE's fossil-energy programs "lost money" coincided with the unsuccessful SynFuels Corporation experiment. More importantly, perhaps, is that all of the NRC study's cost-benefit calculations were based on the highly conservative assumption (where "conservative" here means tending to understate the benefits) that all of the innovations resulting from DOE investments would have materialized from private-sector-funded efforts an average of five years later The NRC study itself emphasized, moreover, that "mechanical" cost-benefit analyses of R&D investments are inherently problematic, for several reasons:

- many of the benefits may be difficult to monetize (as is the case for many types of environmental benefits, for example);

- benefits often will not have fully materialized at the time of any retrospective study;

- R&D investments often yield results that have "option value" that cannot be accurately evaluated.without the benefit of a degree of predictive accuracy that no analyst can claim;

- R&D investments -- even those in efforts later judged as "failures" -- may contribute to the aggregate stock of scientific and engineering knowledge, with unknowable future benefits.

PROMINENT FAILURES AND SUCCESS -- AND LESSONS LEARNED

Clinch River Breeder Reactor[1]

The Clinch River Breeder Reactor (CRBR) was announced by the Atomic Energy Commission in 1972 as the nation's first demonstration of liquid-metal fast breeder reactor plant. The CRBR was estimated to cost about half a billion dollars, with private industry paying for approximately 37 percent of the total cost. Justification for the CRBR was based on projected increases in the price of uranium fuel for the nation's existing light water reactor fleet that would cause the price of nuclear electric power to become prohibitive. By "breeding" more fissionable fuel (plutonium) than it consumed, the pilot reactor would become the technological guarantor of economical nuclear electric power far into the future.

At the project's initiation, however, the AEC's own cost-benefit analysis was not favorable to the CRBR project as a commercial demonstration program. To get a positive net present value, the CRBR would have to be the first step leading to a large program of commercial breeder reactors. This outcome would require a very high rate of electricity demand, no competing technologies, and the disappearance of cheap uranium. The validity of these projects was soon called into question as the growth rate of electric power demand declined and cheap uranium did not disappear. With cheap uranium, there was no need for the CRBR project. By the late 1970s, controversy about the project had risen substantially, in part because of debates over the proliferation of nuclear weapons and the prospect of a domestic "plutonium economy." Escalation of the CRBR costs led to even more controversy because by the end of the 1970s an additional $1.7 billion was estimated to be required for the CRBR to achieve commercialization. The Senate killed the project in 1983 after $1.6 billion had been spent, with an estimated cost to completion of at least another $2.5 billion.

Lessons Learned:

1. The federal government should not be the primary source of funding for energy technology commercialization demonstration projects. Funding should be dominated by the potential industrial beneficiaries of the demonstrated technology. Massive federal funding of megaprojects galvanizes legislative, bureaucratic, and regional champions of the projects to a level beyond the point of productivity or economic justification and invites federal interference in project management.
2. Before a project begins, the proposing industrial team must produce realistic cost, performance, and schedule estimates, including commitment to its portion (majority) of the cost of the project. These estimates must be reviewed by an independent and knowledgeable team before project approval.
3. Before a project begins, clear mutually agreed to technical cost, performance, and schedule goals must be established, along with sound criteria for changing or canceling the project if reasonable progress toward those goals is not met.

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[1] Excerpted from PCAST 1999, pg. 2-17.

4. As a corollary to number 3, an oversight process should be established to provide a periodic independent evaluation of project management, performance, schedule, and cost control.
5. Although federally funded projects cannot be insulated from political interference and "second-guessing," the government should resist making politically determined decisions that compromise the justified continuation or cancellation of energy projects.

Magnetohydrodynamics[2]

This program in the fossil energy division of DOE was targeted at using electromagnetic induction to produce electric power from coal. After the creation of DOE in 1977, MHD quickly became one of its major technology programs. DOE's MHD program was focused on the development of two major test facilities: the Component Development and Integration Facility (CDIF) and the Coal-Fired Flow Facility (CFFF). Between 1978 and 1993, DOE expenditures for the MHD program totaled $1 billion (1999 dollars). Over this same period, private industry cost sharing totaled about $61 million. Cost sharing began in 1986 when private industry was required by legislation to cost share, initially at 10 percent, but increasing to 35 percent by the end of the proof-of-concept program in 1993. Almost half of the DOE expenditures for MHD R&D occurred in the first 4 years from 1978 to 1981, during design and construction of the test facilities. After 1982, Doe did not request any funds for the MHD program from 1982 to 1993, when the program was finally terminated. In those years, the funding came from direct congressional line item additions to the DOE budget. While the MHD program was modestly successful in the proof-of-concept phases, system evaluation studies were indicating that the cost to design, construct, and operate a central station MHD power generation facility was much higher than the corresponding costs for other coal-fired power generation options. In addition to the high costs, the claim for high-cycle efficiencies was questionable. This raised real doubts that the MHD system could compete on an efficiency basis with the advanced gas turbine combined cycles used by the utility industry. These doubts ultimately led to program termination.

Lessons Learned:

1. Substantial funds continued to be spent after 1981 to prove the MHD concept in the face of data that were showing significant technical barriers to the successful development of the concept. At the same time, studies indicated that even if developed, the MHD power generation system would not be competitive on an efficiency or cost basis with alternatives that were already in use by the utility industry. The data suggest that this information led to DOE's decision not to request funding after 1981, except for 1985. Congress continued to fund this program through 1993, however, an indication of the strength of congressional support for MHD.
2. Private sector interest in developing a technology, as evidenced by a willingness to cost share in the demonstration process, must be considered. There was no cost-sharing in the design, construction, and early operation of the costly large-scale facilities.
3. Difficult decisions to terminate programs must be made as early as possible and available funds redirected to the areas of greatest potential.

Advanced Efficient Refrigeration Program[3]

In 1977, DOE initiated an appliance product development program that included emphasis on refrigerator-freezers and supermarket refrigeration systems. Manufacturer involvement was substantial from the outset. DOE targeted both improved components, starting with the electricity-intensive refrigerator compressor, and computer tools for analyzing refrigerator design options. Early successes included a compressor system that achieved 44 percent efficiency improvement over the technology commonly used in refrigerators of the late 1970s. The total funding from 1978-1981 for refrigerator compressor R&D was $1.56 million (1999 dollars). The research was cost-shared with industry through a competitive solicitation. The winning contractor, Columbus Products Company, contributed $550,000 (1999 dollars). Since then, the average electricity consumption of refrigerators has been reduced by more than two-thirds, even as average unit sizes increased, performance improved, and ozone-depleting substances were removed. DOE was an early

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[2] Excerpted from NRC 2001, pg. 190-193.
[3] Excerpted from NRC 2001, pg. 95-99.

and effective leader starting with its 1977 launch of product development. DOE's initial investment helped demonstrate that a full-featured refrigerator could use 60 percent less electricity than comparable conventional units. These successes strongly influenced the enactment of increasingly demanding efficiency standards, first in California and ultimately by DOE itself, under authority of the National Appliance Energy Conservation Act of 1987. Total economic benefits deriving from this program are estimated at $7 billion (1999 dollars). Other benefits include substantial emissions reductions, reduction in energy consumption, improved electric system reliability, and knowledge benefits related to system optimization, R&D on energy-saving components and features, and application to air conditioners.

Lessons Learned:

1. This case study underscores the value to society of integrating RD&D and minimum efficiency standards as an instrument for accelerating technological innovation.
2. Competitive solicitation for cost-sharing can be very useful in public-private partnerships.

Oil and Gas Drilling, Completion, and Stimulation Program[4]

This program began as the drilling research program initiated in 1975 following the Arab oil embargo. The program focused on developing drilling technology to increase domestic oil and gas production. In 1993 it was separated into oil and gas subsections. The current program is targeted at the development of technology to reduce drilling costs, minimize formation damage, reduce environmental risks, reduce surface footprint of onshore and offshore drilling, and improve access to culturally and environmentally sensitive areas. The program has consisted of a very large number of small projects covering almost every facet of the various drilling, completion, and stimulation technologies. Historically, much of the technology is utilized in the oil industry by service companies. The technologies are developed primarily by the oil service companies and oil companies. Industry has indicated its interest in these programs by funding 29 percent of the total expenditures from 1978 to 1999. The cumulative cost to DOE of the oil program from 1978 to 1999 was $48 million and the cumulative cost of the gas program was $31 million, for a total of $79 million. The economic benefits from the oil programs alone are assessed at $2.2 billion. The total economic value of the gas program has not been assessed, but two projects alone (underbalanced drilling technologies and high-temperature measurement while drilling/logging while drilling) realized a benefit of $252 million. Significant environmental benefits have accrued from this program including smaller footprints, reduced noise, lower toxicity of discharges, reduced fuel use, and better protection of sensitive environments. Since these programs are all directed at increasing the production of oil and gas in the United States, they directly contribute to national security.

Lessons Learned:

1. Many small and medium-size firms (such as those in the oil service industry) have limited R&D budgets so government can play an effective role with a relatively small investment in high risk projects to stimulate advances in technologies that can have large positive impact on the industry and benefit the nation. Also, in the oil industry, technology disperses quickly, making it difficult to capitalize on R&D investments without government assistant.
2. The key to an effective program is interaction with and feedback from the industry.

COMMISSION ASSESSMENT

Management Improvements at DOE

Considerable effort has been devoted to implementing the recommendations from the NRC and PCAST and other assessments. In particular, progress has been made in:

- Creating explicit goals and strategic plans for the programs within the broad divisions of Fossil Energy and Energy Efficiency and Renewable Energy;

- Establishing criteria for investment, ongoing performance review, and disinvestment; and

[4] Excerpted from the NRC 2001 study, pg. 193-198.

- Creating mechanisms for internal and external peer review and advice.

Remaining challenges relate primarily to

- better linking of 'stovepipes' in DOE's Divisions and Sections;
- truly coordinating the energy innovation programs of the Department at a high-level;
- setting up stronger systems for review and evaluation;
- compelling more coordination between fundamental and applied energy technology research;
- increasing the investment in science and technology training of current and future staff; and
- fostering more cooperation with other government agencies to make sure that R&D programs are consistent with energy-technology deployment policies.

Much of what is required in these respects will follow if DOE extends and re-energizes its efforts to implement the recommendations of the earlier studies summarized above in Figure 1.

It is, of course, up to the Secretary and the Congress to organize and manage the Department. Recognizing the heavy burden carried by the Deputy Secretary for Energy, the Commission encourages the Secretary and Congress to consider establishing an Under Secretary for each of the core missions of the department: nuclear security, nuclear waste management, energy innovation and policy, and management. An organization diagram incorporating these suggestions is depicted in Fig. 2. Grouping all of the energy innovation activities together is intended to enhance overall coordination as recommended by all three recent reports.[5] Note that in this new organizational formulation, the offices of counterintelligence, intelligence, and security report directly to the Secretary, as proposed to Congress by the Bush Administration earlier this year.

Congressional Earmarking

Although Congress is unquestionably responsible for appropriations, the current practice of non-competitive earmarks that bear little connection to the research goals or plans is harmful and raises questions regarding the public value of funds spent for energy innovation. So-called 'pork-barrel' projects are likely to be undertaken for the wrong (or unclear) reasons, in the wrong place, by the wrong people, with results that are often, at best, unclear. For some energy R&D programs, half of their budget is being earmarked. The Commission recommends that Congressional Leadership seek to ensure that earmarks are consistent with the specific strategic objectives of the affected program.

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[5] The one exception to this grouping of energy innovation activities is nuclear waste clean-up R&D, which should be closely connected to the other programs on nuclear waste management and under the authority of the proposed Under Secretary for Waste Management.

PCAST (President's Committee of Advisors on Science and Technology). *Federal Energy Research and Development for the Challenges of the 21st Century*. John P. Holdren, Chair, Panel on Energy Research and Development, Washington, D.C.: Office of Science and Technology Policy, Executive Office of the President of the United States, November 1997.

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SEAB (Secretary of Energy Advisory Board), *Critical Choices: Science, Energy, and Security,* Task Force on the Future of Science Programs at the Department of Energy, Charles M. Vest, Chair, Task Force. Available for download at: www.seab.**energy**.gov/publications/FSPFinalDraft.pdf. Washington, D.C.: U.S. Department of Energy, October 2003.

SPR (Strategic Program Review), *Energy Efficiency and Renewable Energy Strategic Program Review,* U.S. Department of Energy, Washington, DC, March 2002.

Figure 1 Category	PCAST 1997, *Federal Energy Research and Development for the Challenges of the 21st Century (pgs. 7-24 to 7-33)*	NRC 2001, *Energy Research at DOE: Was It Worth It? (pgs. 62-69)*	SEAB 2003, *Critical Choices: Science, Energy, and Security. Task Force on The Future of Science Programs at the Department of Energy (pgs. 18-25)*
Leadership and Organizational Structure	One person should be in charge of energy innovation activities at the Under Secretary level	Need for more flexibility in the structure of programs	DOE should have an Undersecretary for Science to serve as steward for basic research and connect with applied research programs
Strategic Planning	Create a long-term strategic plan and vision, then define programs, create partnerships, etc.	Develop clear performance targets and milestones, including intermediate performance targets (go/no-go criteria)	Focus on outcomes; more merit-based competition; embark on 3 major, highly-visible research initiatives to promote leadership
Review and Evaluation	Review and evaluation are crucial; minimize inside agency and maximize use of outside advisory bodies. Figure out how to terminate consistently unpromising projects (in PCAST 1999)	Main recommendation of study: Develop and adopt analytic framework to better evaluate existing programs uniformly. Requires better data collection.	Use merit-based decision making
Partnerships	Cultivate more and stronger partnerships with firms, labs, and universities	Continue cost-sharing projects with industry and other partners; try to quantify costs that are shared	More partnerships with industry and academia
Technical Oversight Committees	Use technical oversight committees for each program (including outside experts)	Ongoing evaluation relies on regular peer review by panels of outside technical experts	Regular reviews are necessary
External Peer Review	Do more external peer review of overall strategy and plans	Regular external review is needed, particularly regarding application of analytic framework	Undersecretary for Science should have high-level Science Advisory Board
Coordination Within DOE	More coordination between fundamental and applied technology RD&D through co-funding and co-management of basic and applied research More coordination among technical programs (less "stovepiping")	More coordination with other policies that might promote deployment of advanced technologies	Science programs have historic reputation of being badly managed, fragmented and politically unresponsive
Coordination Outside DOE		More coordination with other government agencies, esp. EPA	
Portfolio Management	Use strategic criteria to determine DOE energy technology portfolio (economic, enviro., security, diversity)	Allocation of RD&D funds requires the application of priorities based on stated policy as well as the exercise of judgment rather than mechanical application of cost-benefit techniques	Focus on three areas: energy production, storage, distribution, management; adv. Computation and simulation for basic science; frontier research facility for basic science
Role of Congress	Many management problems begin with congressional micromanagement of programs, earmarking, and dramatic shifts in budget levels and directives		Congress has not given DOE science budgets the priority merited by their importance; improve outreach capability to Congress, public, and other agencies
Staffing and Technical Skills	DOE staff technical skills should be strengthened through training, targeted hiring, and through staff rotations.		More federal invest. in physical sciences and adv. engineer.; DOE should work to educating future scientists and engineers for careers in DOE-related fields (K-12, undergrad through post-co)
Deferred Maintenance			Program should be established to renew labs because facilities and infrastructure are in a state of decay.

Figure 2: Proposed Organizational Changes to the U.S. Department of Energy